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Slip-and-Fall Accidents During Equipment Maintenance in the Surface Mining Industry

By Thomas J. Albin and W. P. Adams

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SLIP-AND-FALL ACCIDENTS DURING EQUIPMENT MAINTENANCE IN THE SURFACE MINING INDUSTRY

By Thomas J. Albin[1] and W. P. Adams[2]

ABSTRACT

This U.S. Bureau of Mines report identifies potential causes of slip-and-fall accidents occurring during surface mine equipment maintenance and describes the relative roles of direct worker behavior and machine design. The relative roles of human behavior and machine design in the causation of slip-and-fall accidents were determined through analysis of accident records, observations of maintenance worker behavior, and evaluation of mine machinery. From these data, relative risk ratios were calculated. Behavior had a relative risk ratio of 1.5; machine design, specifically access systems design, had a relative risk ratio of 2.2. Of the access systems, ladders had the highest relative risk ratio, 7.0. This study suggests that accident intervention would be most profitably made in improving the design of systems used to access maintenance worker areas of mining equipment.

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INTRODUCTION

PROBLEM DESCRIPTION

Recent research conducted by the U.S. Bureau of Mines has shown that accidents occurring during maintenance of mining equipment constituted 34 pct of all surface mining accidents from 1978 to 1984 (*1*).[3] Does this mean that maintenance is more hazardous than other mining activity? During 1986, the only year for which demographic data regarding miners are available, there were an estimated 27,864 maintenance workers in the surface mining industry (*2-3*). Although these workers accounted for only 6.7 pct of all hours worked, they were involved in 16.8 pct of all surface mining accidents (*4*). Based on these estimates, it appears that maintenance is 2-1/2 times more hazardous than other surface mining activities.

Contemporary mining equipment is quite large, and maintenance workers must move about on it to perform their jobs. A large part of their work is performed in the presence of fluids, fuels, and lubricants. Dusts, ore particles, and other associated debris may also degrade surface footing properties. All of these substances put maintenance workers at risk for slips and falls. Bureau research found that slip-and-fall accidents constitute approximately 20 pct of all surface mining maintenance accidents.

Slip-and-fall accidents, as a group, are more severe than are other mining accidents. A standard definition of accident severity, as used by the U.S. Mine Safety and Health Administration (MSHA), is the sum of the lost workdays plus the statutory number of penalty days assessed to each accident plus one-half the restricted duty workdays. One study found the average accident severity for all surface mining accidents to be 18.5 days compared with 33 days for slip-and-fall accidents (*5*). Thus slips and falls, as 20 pct of all maintenance accidents with an average severity 1.8 times the average, account for 36 pct of all maintenance accident severity.

Slips and falls are clearly an important safety problem that costs individuals and mine operating companies dearly. The individual endures both the economic and physical costs of the accident, while the operating company endures increased insurance costs and losses in productivity. It has been estimated that the average direct cost per case of all surface mining accidents is $14,000 (*6*). If the relationship between accident severity and accident cost is linear, then an average slip-and-fall accident has an associated cost 1.8 times the overall average, or $25,200. This estimate is based on (1) loss in personal income, (2) compensation of wages, (3) death and disability benefits, (4) medical costs, (5) postaccident losses as a result of fatality or amputation, and (6) investigation of a fatal accident (*6*). The estimate does not include the costs of (1) loss of life, (2) fines, (3) lawsuits, (4) loss of equipment, (5) productivity losses due to workplace disruption, (6) productivity losses due to temporary or permanent shutdowns, (7) productivity losses due to inexperienced replacement workers, or (8) long-term followup medical or rehabilitation treatment (*6*).

The expected loss to a mining operator in a given time period can be estimated. During the first 6 months of 1987, individuals employed in all sectors of surface mining operations, including coal, metal-nonmetal, and sand and gravel, with their associated plants and mills, worked a total of 398,179,605 h (*7*). During the same time period, 1,163 slip-and-fall accidents occurred in these same operations (*7*). The expected incidence rate of slip-and-fall accidents per any given unit of time may be obtained from these data by division. It is the usual practice to base the incidence rate on the number of accidents per 100 work years, where a work year is defined as 2,000 h worked (one full-time equivalent) (*7*). Using this method, the expected incidence rate of slip-and-fall accidents in surface mining is 0.58 incidents per year per 100 full-time equivalents. (An alternative method for estimating incidence rates is described in reference 8.) The minimal expected cost of a slip-and-fall accident per 100 full-time equivalents is the product of the probability of a slip-and-fall accident (0.58), times the linearly estimated cost of a slip-and-fall accident ($25,200), or $14,616. Thus, each surface mining operation should expect to incur approximately $15,000 in costs because of slip-and-fall accidents per 100 full-time employees annually.

This $15,000 cost figure can be used to "bench mark" intervention efforts aimed at preventing or decreasing the rate of slip-and-fall accidents. As an example, assume a mine with 100 full-time employees is contemplating spending $20,000 in permanent improvements that would decrease slip-and-fall accidents by 50 pct. This is an initial investment of $20,000 and a reduced expected annual cost of $7,500 ($15,000 \times 0.5$). The expected payback period is 2.67 years, calculated by dividing $20,000 by $7,500 per year (*9*).

However, this example assumes that the miner has some knowledge of the causes of slip-and-fall accidents prior to addressing them, knowledge of the effect on the slip-and-fall incidence rate of remediating them once they are identified, and an idea of the cost of implementing the remediative measures. While the last might be estimated with accuracy, the first two are less well studied in surface mining.

PROBLEM BACKGROUND

Remediation of the causes of slip-and-fall accidents requires knowledge of the kinds of causes and their nature. In a general discussion of accident safety, two diametrically opposed explanations of accident causation are given. The first of these is that "stupid, careless, negligent people are

[3]Italic numbers in parentheses refer to items in the list of references preceding the appendix at the end of this report.

the cause of 90 pct of all accidents and that the tools, machinery, or processes should not even be considered as being primary potential causes" (*11*). The other extreme explanation blames poorly designed products as the cause of accidents. The belief is that products should be so designed that, even in the presence of untrained careless persons, the product will have human fail-safe procedures features that will provide protection for persons from their own errors and negligence (*10*). While these two opposites are recognized as extremes, they serve a heuristic purpose: To what extent are individual behavior and machine design involved as risk factors in slip-and-fall accidents in surface mining maintenance?

A study done by MSHA in 1985 analyzing ladder falls from off-road haul trucks stated that "safe ladder systems are needed to prevent men from falling; however, insufficient training and unsafe work practices appear to be major causes of injuries associated with haul truck ladder systems" (*11*). It is worth noting that the researchers were unable to classify 65 pct of the accidents as to probable cause. Unsafe work habits were defined in this study as (1) missing a step, (2) carrying articles, (3) jumping from the ladder, (4) catching clothing or ring on a step or handrail, (5) not using the handrail, (6) falling from a moving truck and, (7) facing away from the ladder. While the classification of some of these behaviors might be debated, the import remains, individuals engage in risky behavior in the job environment.

Risk may be defined logically as the expected loss resultant from a chosen alternative behavior (*12*), and it may be further divided into objective and subjective risk that often differ (*13*). Objective risk is the verbally expressed level of risk, i.e., "it is unsafe to climb a ladder while carrying an object in my hands," versus the subjective risk assessment, i.e., "I've carried this part up this way a hundred times before without any problem." Behavior clearly plays a role in slip-and-fall accidents, and risk perception logically plays an important role in behavior.

Previous work by the Bureau on slip-and-fall accidents during maintenance has focused on the design of access systems (such as ladders, steps and stairs, and walkways) for mining machines (*14*). Serious design problems, particularly the height of the first step off the ground, were identified and remediative devices were developed.

Risk behaviors associated with slip-and-fall accidents are, currently, not well described. Some are well known, i.e., descending a ladder facing outwards, but there are likely others as yet unidentified. In addition, the risk associated with these behaviors has not been directly assessed. Similarly, machine design problems have typically been ascribed to existing access systems, i.e., the height of the first ladder step above the ground, but it is not clear if other design problems exist.

It is apparent that remediation of slip-and-fall accidents will be necessary. It is also apparent that both behavior, including risk perception, and machine design are probable causes of such accidents, but that their relative importance is unclear. It is important to understand their relative causal roles in order to develop effective remediation strategies that will prevent or decrease slip-and-fall accidents.

OBJECTIVES

This research is part of the Bureau's program to enhance the health and safety of mine maintenance workers. There are two major objectives of this study. The first is to develop a description of antecedent events to slip-and-fall accidents that occur during the maintenance of surface mining equipment. The second is to determine the relative roles of behavior and machine design in slip-and-fall accident causation. These objectives will be accomplished through analysis of accident record narratives and field data.

The description of behavior included identification and description of specific risk behaviors, estimation of the proportion of all behavior that the identified risk behaviors constitute, and finally, empirical estimates of risk resultant to the behaviors.

Machine design was assessed both by compliance of access system design with the guidelines for access systems of off-road equipment described in the Society of Automotive Engineers Standard SAE J185 (*15*) and by the evaluation of sufficiency and adequacy of existing access systems as determined through the analysis of accident records. Empirical estimates of the relative risk of various access system elements were developed.

METHOD

ACCIDENT RECORD ANALYSIS

Accident records, including a short narrative description of the accident, were obtained from the MSHA data base through use of the Bureau's Accident Data Analysis (ADA) program. These accident records were drawn from the surface mining industry, which includes coal, metal and nonmetal, and aggregate mines. All slip-and-fall accidents involving surface mine maintenance workers in the years 1985, 1986, and the first half of 1987 were analyzed. These were the most recent data available at the time of compilation. A total of 1,381 accident records were obtained. Based on 1986 estimates (*2-3*), these records pertain to 18,362 mines and 27,864 workers.

The accident narratives were typically not prepared by the injured individual. They were most commonly prepared by safety officers, next followed in frequency by foremen, and finally by the injured individuals. Some additional caveats regarding the narratives should be noted. The narratives were prepared after the fact. As such, their

accuracy and validity may be fairly questioned. First, it is conceivable, and even likely, that important causal factors have not been included in some of the narratives. Second, the reliability of the narratives may be questioned. Given the free-form nature of the narrative, an individual might note and report widely differing narratives of highly similar events. This problem is further complicated when many different individuals are reporting accidents. Nonetheless, these records do contain information that has an important heuristic value for future research.

The narrative records were read and classified by a single rater (Adams) using a prepared list of operationally defined event codes. This rater is a graduate engineer with approximately 1-year's experience in human factors. In order to assess rater reliability, 100 accident narratives were randomly drawn and classified by a second rater (Albin). The codes for these 100 records were compared with the codes prepared by Adams. A coefficient of agreement (*16*) of 0.93 ($p < 0.001$) was obtained.

Event codes and definitions were created for any events discovered in the course of analysis that did not fit events defined in the original list. The final list of events and their definitions are presented in table 1.

Table 1.–Operational definitions for antecedent events to slip-and-fall accidents

Code	Event	Definition
10	Ladder structural failure	Ladder component failed while in use.
11	Slipped on ladder	Individual slipped while on ladder.
12	Ladder slipped or fell	Portable ladder slipped or fell while in use.
13	Handrail not used	Individual did not use handrail while climbing ladder, stairs, etc. although hands were free.
14	Carrying object while using ladder ..	Individual carried object while climbing or descending ladder, so that hands were not free to grasp handrail.
15	Handrail did not arrest	Handrail friction was insufficient or excessive load on hand gripping rail.
16	Fell from ladder	Individual fell from ladder.
17, 33, 41 ..	Stepped off access system	Individual slipped and fell while stepping from ladder, step, etc. to base surface.
20	Slipped on surface	Individual slipped on mud, ice, etc. while walking on parking lot, pit floor, etc. (not including building floors).
21	Unmarked hazard	Unmarked or unguarded hazard, particularly holes in surface made by missing plates of deck grating.
22	Tripped on uneven surface	Individual tripped on projection from surface.
23	Tripped on grating	Individual tripped when cleats of work boots were caught in grating.
24	Slipped on debris	Individual slipped on debris, scrap, ore, tools, etc. on surface.
25	Slipped on spill	Individual slipped on spilled substance, such as lubricant, coolant, water.
26	Slipped on work surface	Individual slipped on surface of work area (including building floors).
30, 32	Slipped on stairs or step	Individual slipped or fell on stairs or step.
31	Portable stairs moved	Portable stairs moved while in use.
40	Slipped off machine	Individual slipped or fell from machine because of poor surface traction.
42	Slipped on machine	Individual slipped while on mobile or stationary machine and fell on machine.
43	Slipped on machine access system .	Individual slipped and fell while stepping onto ladder, step, etc. from base surface.
44	Slipped on catwalk	Individual slipped on walkway or catwalk.
45	Slipped on deck	Individual slipped on deck of mobile or stationary machine.
46	No escape route	Escape route was not designed into system.
47	Jumped	Individual jumped from one location to another, as in jumping between machines or down from machines.
50	Inadequate workstand	Workstand did not have sufficient surface traction or was lacking a necessary component, such as a guardrail.
51	No guardrail	Individual fell off object, such as workstand or platform because guardrail was not in place.
52	Guardrail structural failure	Guardrail failed because of load.
53	No toe rail	Individual's foot slipped over edge or object, such as tool, dropped off because toe rail was not provided.
54, 64	Structural failure	Failure of structural member not part of access system. Failure of structural member not designed for use as access system but being used for such is coded as inadequate workstand.
55	Inadequate access design	Access system not designed properly to enable adequate access to machine.
60	Unexpected energy release	Individual fell when unexpected energy was released, such as wrench slipping or rope breaking.
61	Work boots not cleaned	Individual slipped and fell because of decreased traction due to mud, oil, etc. on boots.
63	Clothes caught on object	Individual slipped and fell when clothes caught on object.
65	Unknown	Not enough information to classify.
66	Access system not used	Individual did not use access system although one was available.
70	Knee gave way	Individual's knee buckled causing slip and fall.
71	Falling or raising object	Accident caused by falling object, or while individual was raising object.
72	Bumped head	Accident caused by bump to head.
73	Carried object	Individual was carrying object in hands prior to accident.

ASSESSMENT OF WORKER BEHAVIOR

The analysis of accident narrative reports described in the section "Accident Record Analysis" was used to develop a list of direct worker behaviors that were antecedent to slip-and-fall accidents. These behaviors include using a ladder while carrying an object in the hands; jumping from a machine; not using an access system when one is available; and not cleaning oil, mud, etc. off of work boots.

For the field phase of the study, two researchers observed maintenance work activity for a combined 80 h of observation time. During this time, four maintenance workers were scheduled to be filmed while performing their normal duties for 2 h each on 2 separate days over a period of 4 days. Filming was done while maintenance personnel accessed front-end loaders, bulldozers, off-road haul trucks, road graders, power shovels, and various stationary machines such as crushers, etc. In actuality, much of the maintenance work observed during these filming periods took place in areas that were physically inaccessible to the camera. Consequently, only about 2 h film was gathered on each of the four individuals. One individual at a time was filmed, starting on the second and sixth hours of each shift in order to control for time effects. Both the days when filming occurred and the order of filming during the shift were randomly determined for each individual. While the possibility of a Hawthorne effect exists, previous research has suggested that such behavior changes are transient and disappear after repeated observations (*17*).

Behavioral samples were obtained by viewing randomly determined portions of 1 day's videotape of each of the four maintenance workers while they serviced mining equipment. The days used were randomly selected for each individual as follows. Each of the four selected tapes was numbered in sequence. The lengths of the selected videotapes, as indicated by the tape player's incremental counter, were added, in order of sequence, to generate a total tape length. A BASICA program was written to generate a list of 100 random numbers ranging between 0 and 1. Each of these numbers was then multiplied by the total tape length to generate a point at which the observation was to occur. The tape was then viewed at these points. A tally was made of all instances where one of the high-risk behaviors was observed.

During each day that an individual maintenance worker was selected for filming, that individual was under continuous observation by an observer. The observer recorded information on the relative proportions of time that maintenance workers spent in various locations, including various access systems. These locations were (1) on a ladder, (2) on the ground, (3) on stairs, (4) stationary on a machine, (5) on a workstand, (6) climbing on a machine where no prepared access existed, (7) on a walkway, (8) operating a machine, and (9) miscellaneous.

These worker location data were collected continuously on all four maintenance workers over the 4-day period using a systematic random sampling procedure (*18*) at 10-min intervals after a randomly determined starting point. These data were recorded in a notebook.

The objective of this phase of the study was to estimate two proportions: the proportion of high-risk behaviors and the proportion of time spent in various locations. The estimates of these proportions were accomplished via a work-sampling technique (*18*). This method may be used to estimate the precision of the estimate of a proportion using equation 1:

$$N = (p' (1 - p')z^2)/D^2, \qquad (1)$$

where N = number of samples required,

p' = first-guess estimate of the proportion,

z = z-score for any desired confidence interval,

and D = desired precision of the estimate of the proportion, expressed as a decimal fraction and interpreted as the proportion plus or minus D pct.

While z was specified prior to the study as 1.96, and time constraints suggested a maximum sample size, N, of 100, the proportion of risk behaviors was unknown at the beginning of the study, resulting in an unknown degree of precision. It was decided to use a conservative procedure (*18*) to estimate the precision for a sample size of 100 observations. This procedure consists of setting p' equal to 0.5 and solving equation 1 for D. Using this procedure yielded a value of 0.09 for D. This was considered to be an acceptable level of precision, particularly as the true proportion was considered likely to be much less than 0.5, which would result in increased precision of the estimate with a sample size of 100.

MINING MACHINE ACCESS SYSTEM ANALYSIS

Access systems of mobile mine equipment were evaluated for new (1988) and older (pre-1988) machinery. Access systems of the new machines were evaluated with the manufacturers' permission and cooperation at the 1988 MINEXPO show in Chicago, IL. Of the new off-road machines examined, three were front-end loaders and two were trucks. These machines are a reasonable representation of equipment that would be found in a surface mine, with the notable exception of power shovels.

Of the older machines evaluated at a cooperating mining operation, two were front-end loaders and two were off-road haul trucks. All machines were evaluated for compliance with the recommended access system design guidelines published by SAE (*15*). Scoring sheets were constructed for this evaluation, which depicted different access system components and the relevant dimension lines of each. Each relevant dimension of the access system, e.g., ladder width, was given a letter code. The evaluator recorded the site of any particular access system component on the machine, e.g., cab access, and the measurements appropriate to that particular access system element by letter code on the sheet. A sample scoring sheet is shown in figure 1.

Dimensions for each access system element were scored to indicate compliance with the SAE J185 standard. The SAE J185 standard gives minimum, maximum, and recommended dimensions for each access system element. If the access system of a machine was within 10 pct, plus or minus, of the recommended dimension, it was given a score of 1. An access system element whose dimensions were between the maximum and minimum given in SAE J185 but not within a 10-pct range of the recommended dimension was given a score of 2. An access system element whose dimensions were outside the maximum or minimum values was given a score of 3. Each access system component was given a composite score, which was the arithmetic average of its subelements' scores, i.e., the score for a ladder would be the average of the score for step width, handrail diameter, etc.

RESULTS

A complete listing of antecedent events, their associated codes, and the frequency with which they were noted in the accident records is presented in table 2. The total number of events exceeds the number of accidents because some accidents had more than one antecedent event noted.

Direct Worker Behavior

Direct volitional behavior of the individual involved in an accident was noted in 8.9 pct of all accident narratives. These behaviors included descending a ladder facing outward; carrying an object while using a ladder; jumping from a machine; not cleaning mud, oil, etc. from work boots; or not using an access system when one is available.

Using the random sampling procedure described in the "Methods" section, 100 observations were made of maintenance workers' behavior while they were maintaining mining equipment. During these observations, six instances of direct, high-risk behaviors, such as jumping off the machine, were observed. Thus, the estimate of the proportion of high-risk behaviors, as calculated from equation 1, is 0.06, plus or minus 0.05. A summary of all behavioral data from both the accident records and field observations is presented in table 3.

Table 3 indicates that an additional 237 accidents (17.2 pct) had a possible behavioral component, although the behavior was not necessarily that of the injured individual. These events were unmarked hazards, such as removed floor plates, debris on surface, and spills on surface.

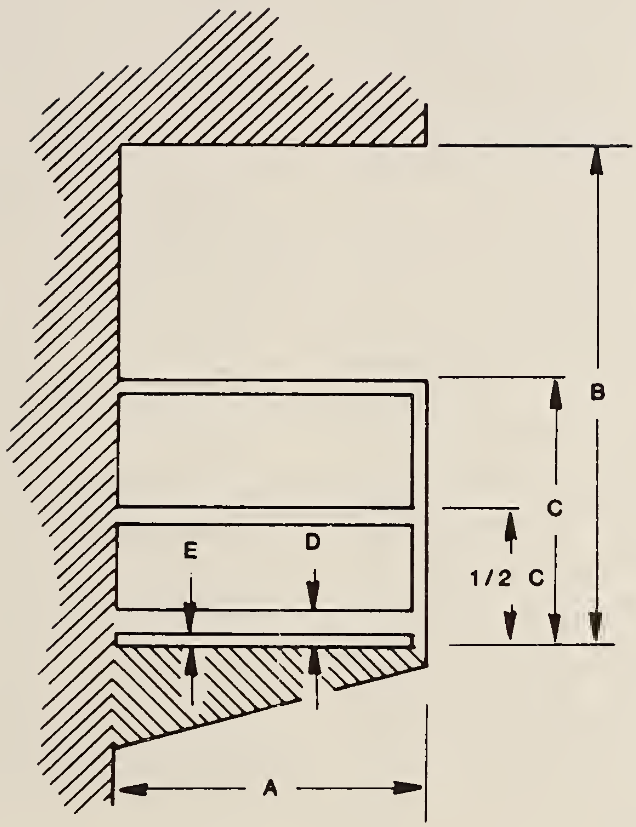
Table 2.–Listing of antecedent events, codes, and frequency noted in accident narratives

Event	Code	Frequency
Slipped on surface	20	170
Slipped off machine	40	170
Unknown	65	141
Slipped on spill	25	129
Stepped off machine	41	116
Tripped on uneven surface	22	104
Unexpected energy release	60	97
Slipped on machine	42	90
Inadequate workstand	50	89
Slipped on work surface	26	82
Slipped on debris	24	73
Carried object	73	62
Slipped on step	32	55
Slipped on stairs	30	53
Jumped	47	51
Fell from ladder	16	50
Slipped on ladder	11	48
Stepped off structure or equipment other than machine	33	39
Ladder slipped or fell	12	38
Access system not used	66	38
Unmarked hazard	21	35
Falling or raising object	71	34
Other structural failure	54	32
Knee gave way	70	27
Work boots not cleaned	61	25
Stepped on machine access system	43	22
Stepped off ladder	17	12
Slipped on catwalk	44	12
Slipped on deck	45	9
No guardrail	51	9
Carrying object while using ladder	14	7
Tripped on grating	23	6
Portable stairs moved	31	6
Guardrail structural failure	52	6
Clothes caught on object	63	6
Ladder structural failure	10	5
Inadequate access design	55	4
Bumped head	72	3
Handrail not used	13	2
Handrail did not arrest	15	2
No escape route	46	2
No toe rail	53	2
Total structural failure	64	1

Table 3.–Antecedent events associated with direct and indirect worker behavior

Event	Code	Frequency
Direct:		
Jumped	47	51
Access system not used	66	38
Work boots not cleaned	61	25
Carried object while using ladder	14	7
Handrail not used	13	2
Total		123
Indirect:		
Slipped on spill	25	129
Slipped on debris	24	73
Unmarked hazard	21	35
Total		237

Model:



Loc:	Loc:	Loc:	Loc:	Loc:	Loc:	Loc:
A ______	A ______	A ______	A ______	A ______	A ______	A ______
B ______	B ______	B ______	B ______	B ______	B ______	B ______
C ______	C ______	C ______	C ______	C ______	C ______	C ______
D ______	D ______	D ______	D ______	D ______	D ______	D ______
E ______	E ______	E ______	E ______	E ______	E ______	E ______

Figure 1.–Example of machine access system scoring sheet (Loc = location). (Courtesy Society of Automotive Engineers (*15*))

Machine Access System Design

The accident narratives indicate that access system elements (ladders, steps and stairs, and walkways) were the location of 291 accidents (21.1 pct of total). Field data indicate that workers spend 10.8 pct of their total work time on ladders, steps and stairs, and walkways. A convenient way of evaluating the relative risk of access system elements is to divide the percentage total of all accidents that occur on an access system element by the percentage of total work time during which the worker is located on that element. The higher the obtained ratio, the more hazardous the access system element. Such an analysis is presented in table 4. This table incorporates the accident narrative data with the data obtained in the field regarding the location of the worker. Ladders, with a ratio of 6.1, and steps and stairs, with a ratio of 2.4, are the most hazardous of the access system elements. The categories of surfaces and machines have been added to this table for completeness.

Measurements were taken on the access systems of eight new machines at the 1988 MINEXPO in Chicago, IL. Three of these machines were front-end loaders and two were off-road haul trucks. Similar measurements of older machines were taken at a cooperating mining operation on two front-end loaders and two off-road haul trucks. These data are presented in table 5. There is a noticeable improvement in the design of the newer equipment access systems. The overall average rating for new machine access systems was 1.7 as compared with 2.0 for older machines. Older truck ladders deviate the most from the SAE J185 guidelines with an average of 2.6.

Table 4.–Slip-and-fall accident location, proportion of total work time in location, and relative risk

Location	Frequency	Pct total accidents	Pct total work time	Ratio
Access systems:				
Ladders	160	11.6	1.9	6.1
Stairs and steps	114	8.3	3.5	2.4
Walkways	12	.9	5.4	.17
Surfaces	252	18.2	38.9	.47
Machines and all else	843	61.0	51.0	1.20

Table 5.–Machine access system ratings

Machine	Ladders	Walkways	Handrails	Average
NEW				
Front-end loaders:				
A	2	1	1.8	1.6
B	2.1	2	2.7	2.3
C	1.5	1	1.5	1.4
Average	1.9	1.3	2.0	1.8
Trucks:				
D	1.5	1.3	1.7	1.5
E	1.8	1.5	1.5	1.6
Average	1.7	1.4	1.6	1.6
Overall average	1.8	1.4	1.8	1.7
OLDER				
Front-end loaders:				
F	1.6	2	NA	1.8
G	1.8	2	1.9	1.9
Average	1.7	2	1.9	1.9
Trucks:				
H	2.5	1.7	2.7	2.3
I	2.7	1	2	1.9
Average	2.6	1.4	2.4	2.1
Overall average	2.2	1.7	2.2	2.0

NA Not available.

Workstation Design

Maintenance workers often gain access to the workplace through the use of workstands or other means of access that are not an integral part of the mining equipment. A common example is a stepladder. A number of such accidents where the workstand design appeared to be at fault were noted in the accident narratives. These incidents were grouped with other records where there were apparent design problems with the workstation. Three hundred instances of workstation design problems were noted in the accident narratives. These data are presented in table 6.

Table 6.–Antecedent events related to workstation design

Event	Code	Frequency
Tripped on uneven surface	22	104
Inadequate workstand	50	89
Ladder slipped or fell	12	38
Other structural failure	54	32
No guardrail	51	9
Guardrail structural failure	52	6
Portable stairs moved	31	6
Ladder structural failure	10	5
Inadequate access design	55	4
Handrail did not arrest	15	2
No toe rail	53	2
Total structural failure	64	1
Total		298

DISCUSSION

This study sought to identify antecedent events to slip and fall accidents in order to develop a better understanding of the causation of such accidents. In addition, it sought to describe the relative roles of worker behavior and machine design contributory to accidents. It was further hypothesized that the perception of risk would affect behavior. Data were collected from two different sources: reports of surface mining maintenance accidents and a field study of maintenance workers.

There were three major findings in this study. First, analysis of the accident narratives showed that 286 accidents, or 20.7 pct of the total number of accidents studied,

occurred on access system elements such as ladders, stairs and steps, and walkways. In contrast, workers spent only 10.8 pct of their total work time on access system elements. Second, a group of direct worker behaviors antecedent to slip-and-fall accidents was identified in the accident narratives. These direct behaviors were found in 123 accident narratives, or 8.9 pct of the total number of accident reports. Field studies indicated that these behaviors constituted approximately 6 pct of all worker behaviors, plus or minus 5 pct. Third, older machines were ranked lower than new machines when measured against the SAE J185 standards, with overall rankings of 2.0 and 1.7, respectively. Ladders and handrails on older off-road haul trucks were particularly problematic.

Finally, during the 80 h of observation, a single slipping accident was observed. This slip did not result in an injury and occurred on a fixed ladder. No direct behavior antecedents were observed prior to this incident.

RELATIVE HAZARD OF DIRECT WORKER BEHAVIOR AND MACHINE ACCESS SYSTEM DESIGN

In order to discuss the relative roles of direct worker behavior and machine design in the causation of maintenance slip-and-fall accidents, a mutual basis of comparison between these two classes of antecedent events must be established. The method used in this report is to calculate relative risk ratios. Relative risk ratios compare the rates of occurrence of an accident in one location or category with the rate of occurrence of similar accidents elsewhere. A relative risk ratio greater than 1 indicates a higher degree of risk associated with that given category. The general formula for relative risk ratios is given in equation 2 (*19*).

$$RR = \frac{(AcC/hC)}{(TAc - AcC)/Th - hC)}, \qquad (2)$$

where RR = relative risk,

AcC = accidents associated with category,

hC = hours worked in category,

TAc = total number of accidents,

and Th = total hours worked.

(The term "category," as used in this equation, refers to location or the type of behavior associated with the accident and hours worked terms.) Conceptually, there is no difference between the proportion of hours worked and the number of hours worked. The field estimates of the proportion of work time spent in various locations or behaviors was substituted for the number of work hours; the total work hours is then equal to unity.

The first comparison made was between direct behavior and use of access system elements. Direct behavior has a relative risk ratio of 1.5, while access systems have a relative risk ratio of 2.2. These ratios are presented in table 7; the calculation of all relative risk ratios is included in appendix A. Access systems are relatively more hazardous than direct behavior. This effect is maintained when the overlap cases are eliminated from the calculation of the relative risk ratios. Based on the accident narratives, there is an overlap of 18 cases between the 2 sets of antecedent events: direct behavior and access system elements. If these cases are eliminated, the relative risk ratios for behavior and access systems are 1.3 and 2.0, respectively.

Table 7.–Relative risk ratios for direct worker behavior and access system elements

Category	*Risk ratio*
Direct behavior	1.5
Access systems	2.2
Direct behavior[1]	1.3
Access systems[1]	2.0
Individual access system elements:	
Ladders	6.8
Stairs and steps	2.5
Walkways	.2

[1]Overlap cases eliminated.

The preliminary ratios in table 4 suggest that some access elements, particularly ladders, are more hazardous than others. Accordingly, relative risk ratios were calculated for individual access system elements. These ratios are also presented in table 7. Ladders have a very high relative risk ratio of 6.8, stairs and steps have a high ratio of 2.5, and walkways have a very low ratio of 0.2. The relative risk ratios confirm the preliminary estimates of the relative hazards of access system elements made in table 4.

The greatest hazard antecedent to slip-and-fall accidents is apparently the access systems, particularly ladders. Reference to table 5 shows that, although improvement has been noted, ladders are tied for the worst overall ranking in terms of compliance with SAE J185 off-road access system standards. Commonly noted ladder deficiencies were the height of the first step above the ground and unequal spacing of ladder rungs.

RISK PERCEPTION

The concept of subjective risk was introduced earlier in this report. Subjective risk is defined as the individual's experience of the hazard level associated with some behavior. The field data gathered on worker behavior give some understanding of the subjective experience of risk associated with behavior. During the maintenance of the mining equipment, six high-risk behaviors were observed during a 105-min observation period. The individuals were engaging in identified risk behaviors at a rate of one behavior every 17.5 min. None of these behaviors resulted in an accident.

During the collection of field data, one slipping incident was observed in approximately 80 h. This incident did not result in an injury.

Earlier, the incidence rate of slip-and-fall accidents was estimated as 0.58 per 100 work years for all surface mine workers. Using the same method, the incidence rate of slip-and-fall accidents for maintenance workers is estimated as 1.98 per 100 work years.

An individual worker's subjective risk experience with regard to hazardous behaviors would be this: A minor, non-injurious slip might be expected, on average, after enough time had elapsed for the occurrence of 274 hazardous, or risk associated behaviors. An accident has a probability of occurrence of 0.019 per work year. Thus, using a binomial estimate, there is about an even chance ($p = 0.46$) that a worker could work 40 years without experiencing a slip-and-fall accident. (The calculations for this probability are shown in appendix B.) It should now be apparent that the subjective level of risk of engaging in risk behavior is, justifiably, quite low.

Similar arguments can be made for estimation of the subjective appreciation of the risk of using access systems. The estimated incidence rate of slip-and-fall accidents while using access systems is 0.46 per 100 work years. (Calculations are shown in appendix B.) If this rate is converted to an annual binomial probability of injury while using an access system of 0.004, the probability of working for 40 years without experiencing a slip-and-fall injury while using an access system is 0.84.

SUMMARY AND CONCLUSIONS

The Bureau studied slip-and-fall accidents that occurred during surface mining maintenance. A list of antecedent events to slip-and-fall accidents was generated from analysis of slip-and-fall accident narratives.

Two main variables were studied as they related to slip-and-fall accidents during surface mining maintenance. These variables are the direct behavior of the individuals involved in the accident and the design of the access systems. The use of access systems was found to have a higher relative risk ratio than the direct, hazardous behaviors identified from the analysis of the narratives. Ladders were identified as the most hazardous of access systems. Improvement in the compliance of new equipment access systems with SAE J185 guidelines was noted, but the access systems of older equipment, particularly off-road haul truck ladders, are still problematic. Subjective risk values were estimated for maintenance workers; the obtained values were quite low, suggesting that individuals will routinely engage in risk behavior without significant expectation of injury.

While the probability of a slip-and-fall injury is small for any individual maintenance worker, it is cumulative for a group. The probability of a maintenance worker sustaining a slip-and-fall injury in a company with five maintenance workers is 0.095 during any year. Thus, it is probably more reasonable for a company to be more sensitive to accident risk than an individual because the expectation of loss is greater.

Given that a company is more likely to be sensitive to the risk of slip-and-fall accidents, what strategies should be taken to improve slip-and-fall safety? The first priority, based on the findings of this study, would be to improve the quality of access system elements, particularly ladders. A reasonable approach might be to bring them into compliance with the SAE J185 guidelines. The second priority would be to make an effort to change the subjective risk perception of the maintenance workers. Training programs have been described (*20*) that effectively teach workers to recognize hazards and to change their behavior accordingly.

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APPENDIX A.–SAMPLE CALCULATIONS OF RELATIVE RISK RATIOS

Direct Behavior

$$\frac{(123/0.06)}{(1{,}381 - 123)/(1 - 0.06)} = \frac{2{,}050}{1{,}338} = 1.5$$

Access Systems

$$\frac{(286/0.108)}{(1{,}381 - 286)/(1.0 - 0.108)} = \frac{2{,}648}{1{,}228} = 2.2$$

Direct Behavior Accidents With Overlap Removed

$$\frac{(105/0.06)}{(1{,}381 - 105)/(1 - 0.06)} = \frac{1{,}750}{1{,}357} = 1.3$$

Access System Accidents With Overlap Removed

$$\frac{(268/0.108)}{(1{,}381 - 268)/(1.0 - 0.108)} = \frac{2{,}481}{1{,}248} = 2.0$$

Individual Access System Elements

Ladders:

$$\frac{(160/0.019)}{(1{,}381 - 160)/(1.0 - 0.019)} = \frac{8{,}421}{1{,}245} = 6.8$$

Stairs and Steps:

$$\frac{(114/0.035)}{(1{,}381 - 114)/(1.0 - 0.035)} = \frac{3{,}257}{1{,}313} = 2.5$$

Walkways:

$$\frac{(12/0.054)}{(1{,}381 - 12)/(1.0 - 0.054)} = \frac{222}{1{,}447} = 0.2$$

APPENDIX B.–CALCULATION OF PROBABILITY OF SLIP-AND-FALL ACCIDENT HAPPENING TO INDIVIDUAL DURING 40-YEAR PERIOD

The probability that an individual will experience a slip-and-fall accident during any year is 0.019. Thus, the probability that a slip-and-fall accident will not happen is 1 - 0.019 = 0.981. Each year is assumed to be independent of every other year. The probability of working n years without a slip-and-fall accident is 0.981 raised to the nth power. The probability of working 40 years without a slip-and-fall accident is thus 0.981 raised to the 40th power, or 0.46.

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